A NOVEL REFLECTOR BASED DIGITAL BEAMFORMING SAR SYSTEM ROBUST AGAINST FEED FAILURES

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1. INTRODUCTION

Synthetic aperture radar imaging is a vastly developing discipline, where information from distant objects can be retrieved contactless. Especially in the field of spaceborne earth observation missions the performance requirements in terms of revisit time and image resolution continuously increase. Since the radar antenna naturally represents the interface between the scattered electromagnetic energy and the radar signals after reception, a careful design of the antenna is one key step in the conception of an efficient SAR system. A requirement directly affecting the antenna design is the designated revisit time of the SAR satellite. For applications like earth system dynamics monitoring [1], a short revisit time is desired, which in turn rises the need of large swath widths. At the same time scientists are interested in a high information content of the SAR signal. This is traditionally achieved by increasing the signal bandwidth resulting in a higher resolution of the SAR images. Large swath widths and high azimuth resolutions are contradicting requirements for conventional SAR systems. This SAR inherent restriction can be overcome by digital beamforming (DBF) techniques [2, 3].

Of increasing interest for SAR applications become large reflector antennas in combination with feed arrays [4, 3, 5]. Fig. 1 sketches the operation principle of a spaceborne SAR system in sidelooking geometry. On transmit a broad beam is generated in order to illuminate the entire swath, while on receive a narrow high gain beam is scanned across the swath. This mode of operation is known as SCORE, first suggested in [6] and further developed in [7] and [8].

Reflector systems are already a mature technique for communication satellites. Reflector antennas typically generate a shaped beam due to the mechanical molding of the reflector dish. That means, for any given feed position, only a certain solid angle can be illuminated. Therefore a set of multiple feed elements is required in order to cover the complete region of interest. This technology is considered as baseline for Tandem-L [9], a mission proposal for an interferometric L-Band radar instrument. In [10] a reflector based Ka-Band system for high resolution Earth observation applications has been investigated. Evidently such systems are severely handicapped in case of a feed element failure. A dropped out element would cause a 'blind' spot in

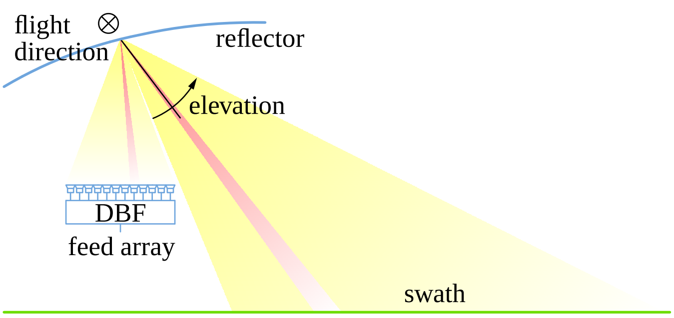

Fig. 1. System operation of a reflector SAR system in a sidelooking geometry. On transmit a wide beam (yellow) illuminates the entire swath, while on receive a narrow high gain beam (red) follows the pulse on ground.

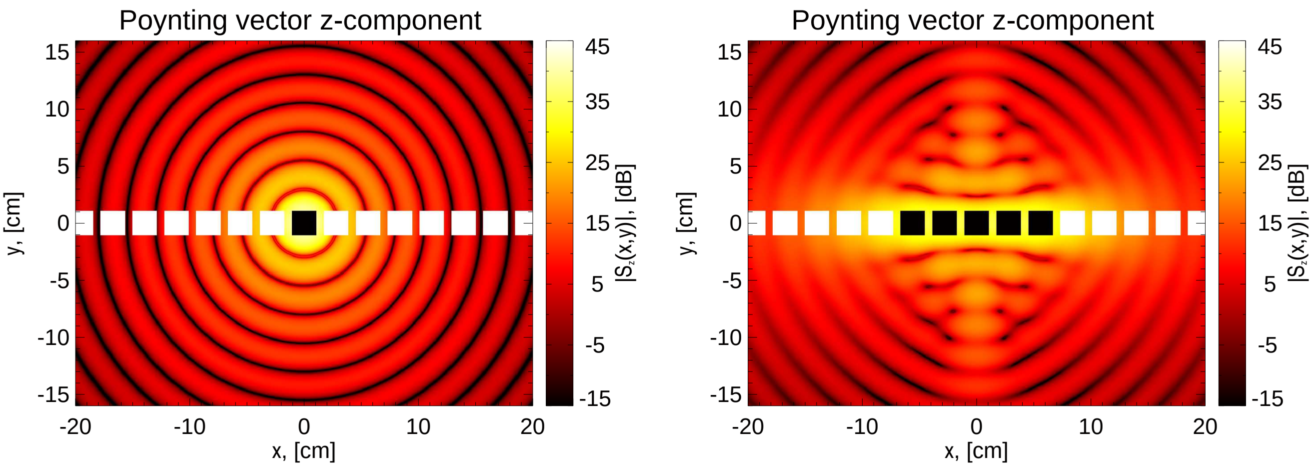

Fig. 2. Left: Power flux density in the focal plane of a parabolic reflector resulting from an incident plane wave. The quadratic patches symbolize the elements of the feed array. Almost the complete electromagnetic power is concentrated around the black feed element in the center of the array. Right: Example of a defocused reflector antenna with two foci. Here the electromagnetic power is distributed over several black colored feed elements.

the antenna footprint. Therefore, state-of-the-art systems are planed with redundant receiver hardware. Clearly this option poses a considerable increase of the costs for satellite SAR systems. Moreover, the redundant electronics, as for example additionally required switches, will produce losses.

The most widely established spaceborne SAR antenna is the planar array antenna. This kind of antenna is very robust against a single or even multiple element failures in terms of beam shape stability. The drawback is clearly that the antenna size required to realize a high-resolution wide-swath SAR system can render a SAR mission infeasible concerning the costs. Consequently, an antenna design is needed, which combines the robustness against element failure of a planar array antenna with the high gain of a large unfoldable low-weight reflector antenna. This concept involves a defocusing of the individual element beams by utilizing a new reflector surface.

It is the goal of this paper to introduce a concept to increase the permissiveness of a reflector antenna based SAR systems against feed element losses. This concept involves an innovative design of the reflector dish. In conjunction with digital beamforming techniques this reflector concept unfolds its full potential in terms of wide-swath imaging capability.

2. DEFOCUSED REFLECTOR ANTENNAS

The concept of defocusing a reflector antenna is not new. Publications like [11, 12, 13] achieve a defocusing by moving the feed out of the focal point and leave the shape of the reflector antenna unaltered. The advantage is that conventional reflectors with paraboloidal, cylindrical or corner surfaces can be utilized. If however a defocusing is desired in only one dimension, elevation in this example, a simple displacement of the feed array would not be satisfying, since the pattern tends to symmetrically defocus in all dimensions. For example a paraboloidal reflector with an axially shifted feed will, compared to the focused case, generate a broader rotational symmetric Bessel-like beam.

Here the defocusing is achieved by shaping the reflector dish itself. One possibility is to construct a reflector with two foci. Fig. 2 on the left shows the power flux density in the focal plane of a conventional parabolic reflector antenna, with a single focus, generated by a plane wave incident antiparallel to the rotational axis of the reflector. The quadratic patches represent the individual elements of the feed array. Only a single element, colored in black, receives the main part of the electromagnetic power. In contrast on the right side of Fig. 2 the power flux density for a reflector with two foci is shown. In this case the feed

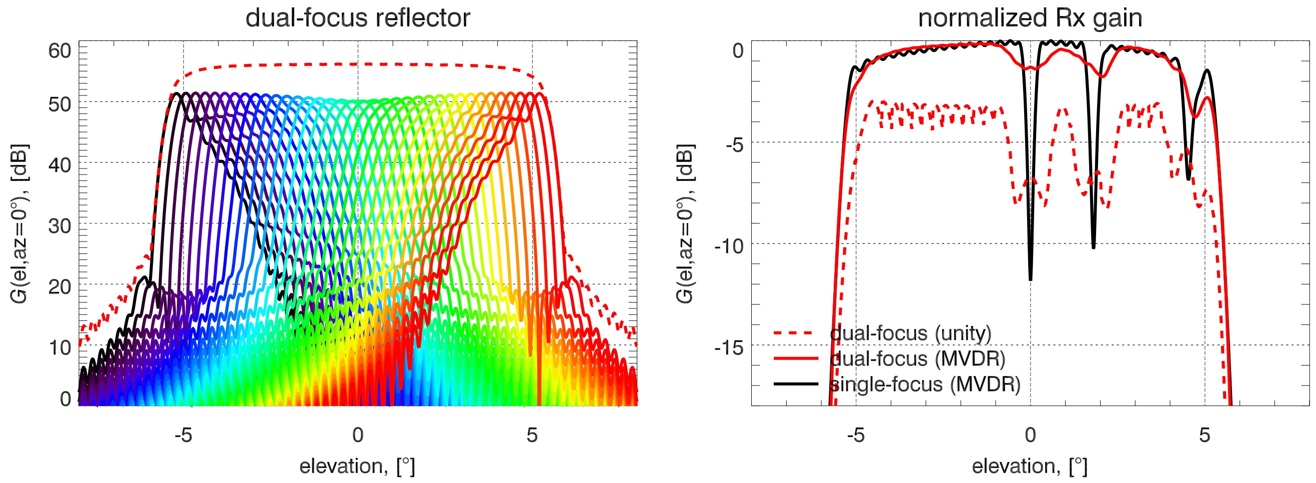

Fig. 3. Left: Individual reflector antenna gain patterns in the elevation plane for the dual-focus reflector. The dashed envelope represents the gain pattern after digital beamforming. Right: Comparison of the gain patterns of the conventional and the dual-focus reflector after digital beamforming, when elements 18 (center element), 24 and 33 have dropped out.

elements are placed in the plane through either of the foci. It can be observed that the electromagnetic power is smeared in the x-dimension, corresponding to elevation, as intended. In case of an black colored element failure the remaining black colored elements still receive enough electromagnetic power in order to maintain SAR operation.

3. PERFORMANCE

Aside from a broadening of the antenna beams, defocusing a reflector antenna always involves a loss in gain. The individual elevation gain patterns versus elevation scan angle for a reflector antenna with 35 feed elements is shown in Fig. 3 on the left. Compared to a conventional single-focus parabolic reflector antenna the gain loss is in the order of four to five dB. However, with digital beamforming techniques the high gain can be recovered as indicated by the dashed curve. In case of feed element failures the gain loss after digital beamforming is much smaller than with the single-focus reflector, as presented in Fig. 3 on the right. Here a beamforming technique, known as minimum variance distortionless response (MVDR) [14] beamforming has been utilized. The dashed red curve represents the most rudimentary beamforming, here called 'unity', when feed elements are simply turned on or off. This result gives reason to the conclusion that DBF techniques utilizing phase and amplitude information are required.

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